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A New Light Enhancement Coating Formulation to be used for TATB Detonation Front Detection

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Abstract. This poster describes a light enhancement coating applied to aid in the detection of the detonating front as captured by streak cameras. There is a discussion of the coating requirements (application technique, pot life, cost, powder availability, worker safety, and environmental concerns) that constrained us towards the final product. Streak images of detonating half coated, half-bare charges are shown to evaluate the light gain.

Introduction

Most conventional high explosives provide sufficient light at the detonating front to allow direct observation by streak cameras. However, researchers[1&2] have determined that TATB requires a light enhancement coating. It has been long known that air gaps produce light in the presence of a shockwave and early attempts to produce a "light enhancement" coating centered on methods to trap air. Cigarette papers and coatings of sand were initially tried, but in an effort to eliminate temporal and spatial distortions, Aluminum Silicofluoride, $Al_2(SiF_6)_3$ coatings became the standard. Bloom[3] ultimately presented the formulation that most of the DOE complex adopted and further determined a shock threshold for obtaining a repeatable "flash". Unfortunately, in recent years, Aluminum Silicofluoride (ASF) has had limited availability and reserve supplies have been dwindling. This work presents a new alternative light enhancement coating based upon alumina (Al_2O_3) with the use of alumina first suggested by Krutchmer and Kramer[4], but never pursued.

The initial ASF mixture suggested by Bloom used Kodak Photo-Flo with poly-vinyl alcohol (PVA) surfactant/binder in an aqueous solution. However, this lacquer exhibited poor pot life because the polymer solution tended to gel upon standing. This resulted in a coating formulation that increased in viscosity over time causing difficulties in application and yielded a non-reproducible coating thickness. This improved alumina formulation uses a methyl cellulose 400 (MC-400) surfactant/binder to provide suspension of the particles in solution, good wettability of the coating to the surface, and to act as a binder in the final coating.

Formulation

An effective spray coating process has been developed with a water carrier to minimize inhalation and fire hazards and to coat in an environmentally correct way. While developing the alumina coating, magnesium oxide (MgO) coatings were also investigated and they were found to react with the aqueous carrier solution changing particle size over time. Alumina was found to be better overall choice because of its wide spread application as a polishing media, thus making it more readily available in a range of particle sizes and morphologies.

The final composition after testing a number of sources resulted in 12.0 g of alumina (5.2 micron, Buehler), 0.15 gram of MC-400 (Aldrich), in 60 ml of distilled water. The particle size of alumina was found not to change when the material stands in aqueous solution for up to two weeks or stirred at room temperature for 16 hours. The morphology of the 5.2-micron alumina is shown in Figure 1 and the stability of particles in solution is shown in Figure 2.
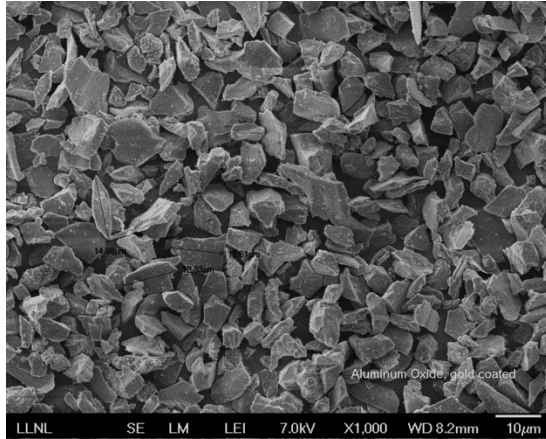

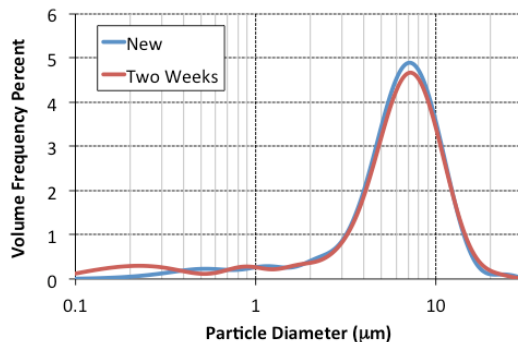Fig. 1. Scanning electron microscope image of 5 micron alumina used in this study.

Fig. 2. Particle size distribution of newly formulated alumina coating and two-week old coating solution.

Application

The stock solution for coating was prepared as follows. Distilled water (400 ml) was added into a 500-ml Erlenmeyer flask equipped with a magnet stir bar. With vigorously stirring, 8.0 g of methyl cellulose (MC, Aldrich, lot 18804-2) was added in one portion and the mixture was stirred at room temperature until a clear solution was reached (needed 5-10 hours). This produces the methyl cellulose stock solution in a concentration of 20.0 mg/cm.

Ten grams (10 g) of aluminum oxide (Al_2O_3, Buehler, 5.0 micron, lot 40-6605-050-080) was added to 16 ml of the MC stock solution in a flask. The flask is sealed and shaken on a Vortex Mixer until all the powder is suspended in the aqueous MC solution. The solution is then transferred into the jar of a Badger Model-150 airbrush, which was used to apply the coatings.

Coating thickness was measured on flat aluminum plates using both laser and white light profilometry with both methods providing comparable results. The laser profilometer was an Optimet Metrology Ltd. ConoScan 3000 and the white light profilometry was a Zemetrics ZeGage 3D optical profiler. Measurement of coating thickness on non-flat parts was attempted, however, depth of field and field of view issues limited the resolution in determining coating thicknesses. Figure 3 shows the results of the coating thickness measurements with the average for each measurement for a given weight of coating.
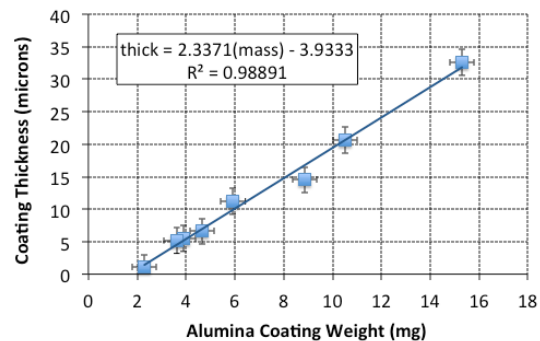

Fig. 3. Coating thickness versus mass for alumina. Note that the sprayed area was 300 mm^2, which is approximately half that of the window in the hemisphere mask shown in Figure 4.

A mask was fabricated for the explosive hemispheres that were to be spray coated (Figure 4). The mass of coated hemispheres were determined gravimetrically and the thickness calculated from the exposed area yielding a quantifiable manner in which to discern the various coatings in test fire as shown in Figure 3. In the future we will perform this same work on the output of aluminum-cupped detonators, which will allow for use of profilometry to determine coating thickness. For reference, the total mass of the TATB hemispheres used here is 26.1 g and the highest coating weight was 24.4 mg representing less than 0.1% of the total explosive weight.
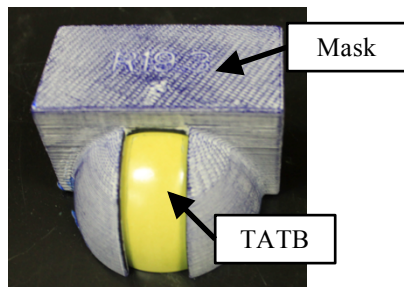

Fig. 4. Fixturing to mask TATB hemispheres for spray coatings of the light enhancement coating. The approximate area of the mask is 300 mm^2.

Equivalency Study

An equivalency study with ASF was developed once a formulation for the light-enhancing coating that provides a homogeneous, reproducible coating had been finalized. This experimental study was performed to determine if the new formulation of alumina provides sufficient light to be considered equivalent to or better than ASF, which has been used at LLNL for light enhancement since the 1970s. Our primary objective was to determine if the alumina coating provides the same or better resolution in calculating the time-of-arrival of shocks on surfaces versus our historical ASF coatings. This study was developed under the assumption that a thicker coating would act as a delay on the measured shock arrival time; therefore, we strove to minimize the thickness while still maintaining adequate light intensity. From a practical standpoint, we also focused on a coating

application process that gave consistent results without being onerous.

The experimental setup used in the study is shown in a simple diagram in Figure 5. Ultrafine TATB powder having a surface area greater than 2 m^2/g (BET method) was pressed into hemispheres having a density of 1.8 g/cm^3 (93% TMD). Hemispheres of TATB were chosen for this study because many experiments performed at LLNL on TATB are spherical. The hemispheres were initiated using the output of a RISI RP-80 exploding bridgewire or EBW detonator. The RP-80's 0.18-mm thick aluminum cup was spaced 1.6 mm off of the TATB hemisphere with a piece of PMMA so that it acts as a flying plate initiator for the hemisphere.
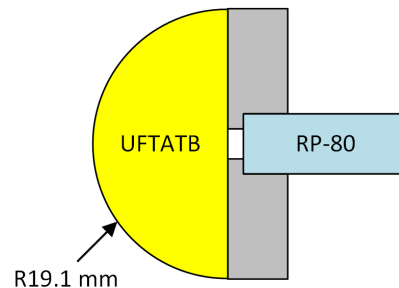

Fig. 5. Setup used for alumina coating study. A PMMA (gray) locator held the RP-80 detonator in place on the TATB hemisphere.

We had hoped to measure the coating thickness on the hemisphere using an optical profilometer, but this proved more difficult that anticipated. The thickness measurements shown earlier on flat aluminum plates give a rough indication of how thick the coating is on the hemispherical surface.

A Cordin Model 132 rotating mirror camera with Kodak TMAX P3200 film was used to measure the streak image recorded across the hemispherical surface of the TATB. The film is then scanned on an Epson flatbed scanner with the film placed between two panes of glass to ensure it is flat. The film is scanned at a resolution of 2,400 dpi, saved as an eight-bit gray scale TIFF and subsequently analyzed using a threshold finding

program that finds the shock wave arrival time and change in level of light intensity.

Results

A total of 10 boosters were fired with weight coatings of alumina ranging from 2.25 mg to 24.4 mg, versus the control samples of (traditional) hand painted ASF, or no coating. Figure 6 shows the time in nanoseconds for the light intensity to increase from a baseline level to ~50% of the peak. This was calculated as the time from where the intensity was a standard deviation above the maximum value of a moving average before the shock arrival time to approximately half of the full light intensity. As can be seen in Figure 6, as the coating weight and thickness increase, there is no delay in the build-up of the intensity of light. It was unknown if the thicker coatings would delay output of the air or slow the jump from no light to full intensity light. Of importance to our study is that the alumina coatings were equivalent in their intensity and rate at which they flashed to the historical ASF coating. The relative quick build-up in intensity of the light allows for higher accuracy using a threshold finding routine and minimizes the inaccuracy in determining an absolute time of arrival of the shock wave as the shock arrival time is distinct.
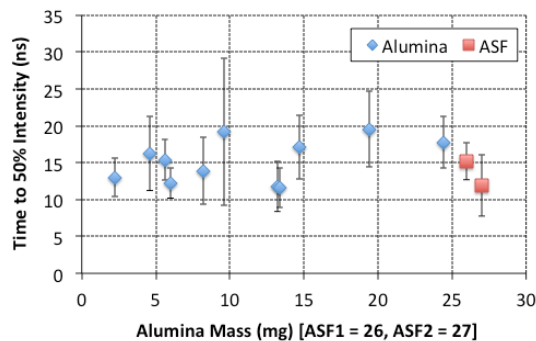

Fig. 6. Time to 50% light intensity for various coating thicknesses of alumina compared to existing hand-painted ASF coating (two shots)

Figure 7 shows the absolute function time of the detonator and TATB hemisphere to the approximate pole of the hemisphere. For coatings where half of the hemisphere was coated with one coating (either ASF or alumina) and the other coated with another weight of alumina, the pole was taken as slightly off center to ensure it clearly represented either alumina or ASF. Figure 7 shows an apparent trend of longer function times for thinner or lower mass coatings. This is counter-intuitive, as we would assume that a thicker coating would be slower. Analysis of over 60 shots on equivalent TATB boosters using the same firing system, but with ASF coatings, shows that the difference from minimum to maximum function time is on the order of 50 nanoseconds. The data here shows the same variation from minimum to maximum and there is insufficient data to conclude a trend exists.
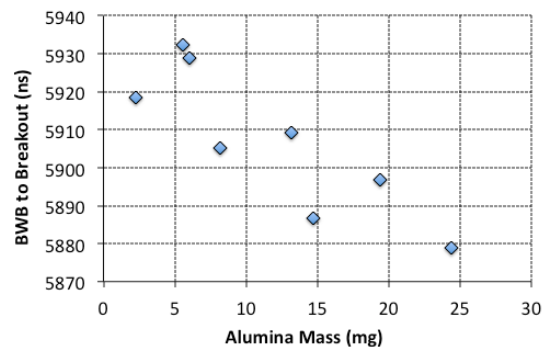

Fig. 7. RP-80 bridge-wire burst (BWB) to arrival time of the detonation wave at the pole of the hemisphere as a function of different weight alumina coatings. ASF has a BWB-Pole time of 5920 ns.

Further shots will be fired in order to determine if the trend is real. These will use a large capacitor bank to propel flat laminate flyers into plates coated with different thickness alumina to verify that there is no variation due to thickness. This work could not be completed in time for this paper.

Figures 8-15 show the breakout profiles from TATB hemispherical charges coated with various weights of alumina with time increasing from top to bottom. All weights (and thicknesses) of coating provide sufficient light to discern a shock arrival time accurately that also works well with automatic threshold finding programs. For comparison we also include a comparison against

uncoated TATB to show the light enhancement provided by the coating.
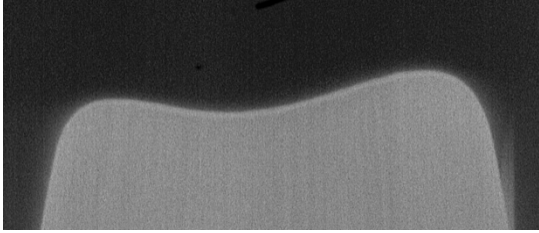

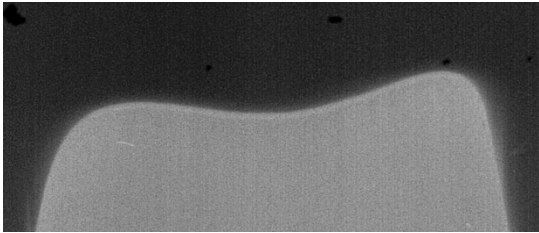Fig. 8. 24.4-mg alumina coating
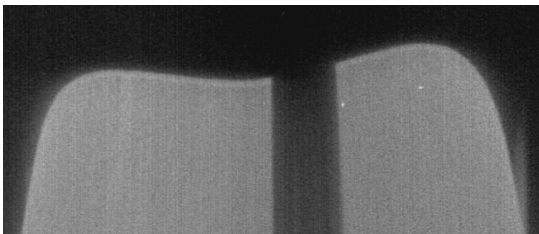

Fig. 9. 19.4-mg alumina coating

Fig. 10. 14.7-mg alumina coating. Off-center on the right side is minimally coated with alumina for comparison.
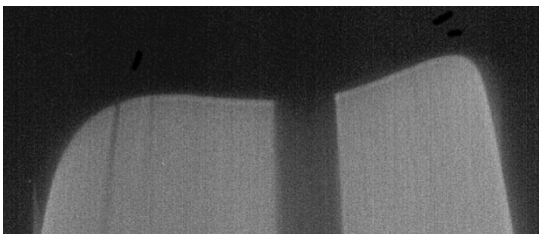

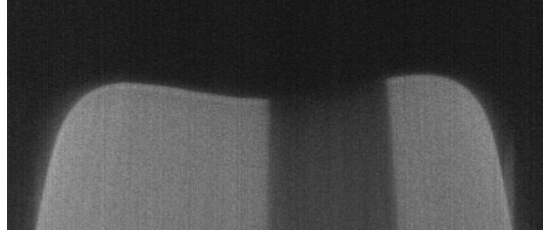Fig. 11. 9.6-mg alumina coating. Off-center on the right side is minimally coated with alumina for comparison.

Fig. 12. 8.2-mg alumina coating. Off-center on the right side is minimally coated with alumina for comparison.
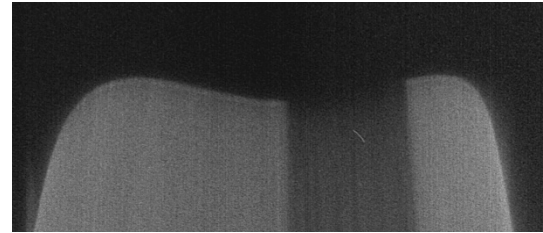

Fig. 13. 4.6-mg alumina coating. Off-center on the right side is minimally coated with alumina for comparison.
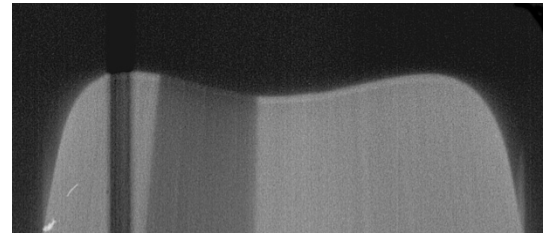

Fig. 14. 13.2-mg alumina coating. Off-center on the left is alumina coated with four passes of the spray gun for comparison.
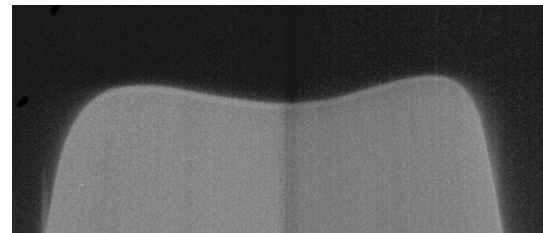

Fig. 15. Left side is coated with 13.35 mg of alumina and the right side is coated with 2.25 mg of alumina.

Figures 16 and 17 show a comparison of alumina coatings with the historical ASF coating. Both shots show the alumina to provide a more distinct

edge giving the shock arrival time, though that provided by the ASF is sufficient.
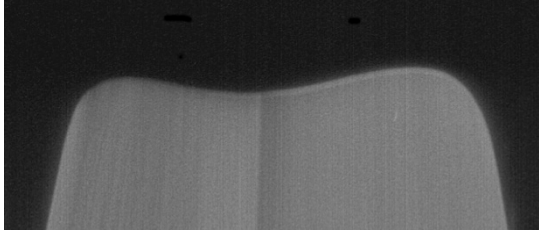

Fig. 16. Left side is coated with ASF and the right side is coated with 5.59 mg of alumina.
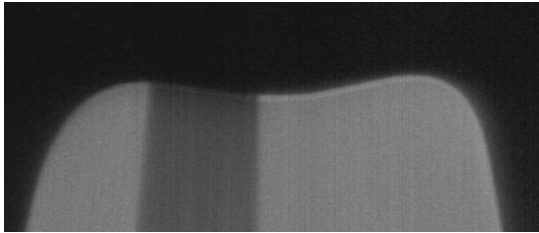

Fig. 17. Far left side is coated with ASF and the right side is coated with 5.99 mg of alumina. The lightly coated region is alumina coated with four passes of the spray gun.

Conclusion

We have developed a new light-enhancement coating formulation to replace ASF. The new coating provides a homogeneous thin coating that is reproducible to apply to charges whose output is being measured using streak cameras. A number of hemispherical charges of TATB were fired that show that the output light intensity is consistent and defines a sharp streak edge regardless of weight or thickness of the coating.

Future work is planned to investigate the absolute timing, i.e., to determine if there are any delays associated with different weights of coating. Work also will be performed that investigates the minimum shock pressure to ionize the air providing light. We expect that we will get results similar to those for ASF where the minimum pressure was found to be 2.93 GPa.

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